EARTH TECH
5555 Glenwood Hills Pkwy SE
PO Box 0874
Grand Rapids, MI 49588-0874

FACSIMILE

Date: August 1, 1994

To: Leah Evison
Fax #: 312-886-4071
Company: U.S. EPA

From: Liz Bartz
Ext #: 404
Location: GRAND RAPIDS, MI
Sending From Fax #:
☒ (616) 942-6499 - Glenwood Bldg
☐ (616) 949-6023 - Eagle Bldg

Project #: 04011-05
Subject: Statistical Methods for Ground Water Sampling

Comments: Attached is some language regarding the statistical methods available for evaluating the significance of arsenic concentrations in ground water at the Albion-Sheridan Township Landfill site.

If you do not receive 5 pages (including cover page), please call us as soon as possible @
(616) 942-9600 - Glenwood Bldg or (616) 940-4300 - Eagle Bldg

EARTH TECH

STATISTICAL EVALUATION OF ARSENIC IN GROUNDWATER

Concentrations of arsenic in wells MW06SB, MW08SB, MW09SB, and MW16SB will be compared to intrawell baseline concentrations using combined Shewhart-cumulative sum (CUSUM) control charts (U.S. EPA, February 1989; p. 7-5). Control charts are recommended by the U.S. EPA as "an effective technique for monitoring the levels of a constituent at a given well over time" (February 1989; p. 7-1). Once constructed, control charts can be evaluated graphically over time, allowing trends and changing conditions to be easily detected. Control charts are appropriate for the evaluation of frequently detected parameters and are particularly useful for evaluating naturally occurring parameters.

Basic assumptions underlying the use of control charts include the assumptions that the data being evaluated are normally and independently distributed. Therefore, baseline arsenic data will be evaluated for distributional assumptions on a well by well basis prior to completing the control charts using the Shapiro-Wilk Test of Normality (U.S. EPA, July 1992; pp. 9-12).

The procedure for constructing Shewhart-CUSUM control charts, described in detail in U.S. EPA guidance (February 1989; pp. 7-7 and 7-8), is summarized below. Throughout this section, the data to be collected after baseline concentrations are established are referred to as "foreground data." To construct the control charts, the following variables will be calculated:

$$Z_i = \frac{(x_i - \bar{x})}{s}$$

$$S_i = \max\{0, (Z_i - k) + S_{i-1}\}$$

where

Z_i	=	the standardized Shewhart value at sample event i,
S_i	=	the CUSUM value at sample event i ($S_0 = 0$ prior to the first foreground sample event upon completion of baseline sampling),
x_i	=	individual foreground concentration at sample event i,
$\bar{x}$	=	mean of intrawell baseline data,
s	=	standard deviation of intrawell baseline data, and
k	=	1, a reference value recommended in U.S. EPA guidance (February 1989; p. 7-8).

The standardized Shewhart value, Z_i, represents the number of standard deviations an individual foreground concentration of arsenic falls from the mean concentration of baseline data and is, therefore, sensitive to rapid increases in arsenic concentrations. The CUSUM value, S_i, is more sensitive to gradual increases or shifts in concentrations over a longer span of time because it accumulates positive deviations from the baseline mean. That is, if several positive Z_i values occur consecutively (because foreground concentrations are consistently higher than the baseline mean concentration), the CUSUM value will continue to grow until concentrations decrease and offset the accumulated value. However, some flexibility is built into the CUSUM value by accumulating only positive deviations which are more than one standard deviation from the baseline mean. The value of k represents this allowable deviation from the baseline mean.

Once the intrawell baseline data sets are complete, values of Z_i and S_i corresponding to the first foreground sample event (where i = 1) and all subsequent sample events will be plotted versus time. The control charts will then be evaluated for evidence of a statistically significant increase. The following limits will be used to evaluate the standardized Shewhart value and the CUSUM values as recommended in U.S. EPA guidance (February 1989; p. 7-8):

what about decrease?

SCL = 4.5, the Shewhart control limit, in units of standard deviation;

h = 5, the decision interval value for the CUSUM;

A value of S_i which exceeds the CUSUM decision interval value of 5 will indicate a statistically significant increase in arsenic concentrations. However, a single value of Z_i which exceeds the SCL of 4.5 will not be considered a statistically significant increase since Z_i is more sensitive to sporadic changes in ground water quality. Because the nature of ground water monitoring statistics is such that occasional individual outlier values occur due to the many potential sources of variation in handling and processing of samples, the conclusion that a statistically significant increase has occurred will not be made until two successive Z_i values exceed the SCL of 4.5. This "two-in-a-row" rule is described in the technical report *Evaluation of Control Chart Methodologies for RCRA Waste Sites* (Starks, 1989; p. 21). Therefore, if Z_i exceeds the SCL but Z_{i-1} did not exceed the SCL, the current result will be flagged for confirmation by the next quarterly event and the sampling event will be considered "questionable."

If a control chart indicates a "questionable" sampling event or statistically significant change, monitoring data for arsenic may be evaluated for seasonal effects and, if detected, adjusted for prior to reconstructing the control chart. Although seasonal effects are difficult to accurately assess based on less than two years of data, they may be more fully evaluated as more data become available for each well.

REFERENCES

Starks, T.H. (1989; January) *Evaluation of Control Chart Methodologies for RCRA (Resource Conservation and Recovery Act) Waste Sites*. Environmental Research Center, University of Nevada, Las Vegas. Sponsored by Environmental Monitoring Systems Laboratory - LV, NV, Office of Research and Development, U.S. Environmental Protection Agency, Las Vegas, NV.

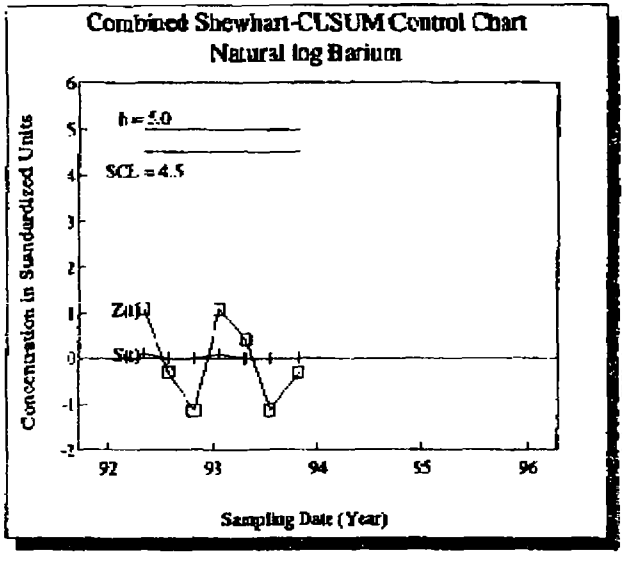
U.S. Environmental Protection Agency (U.S. EPA) (1992; July) *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities -- Addendum to Interim Final Guidance*. Office of Solid Waste, Permits & State Programs Division.

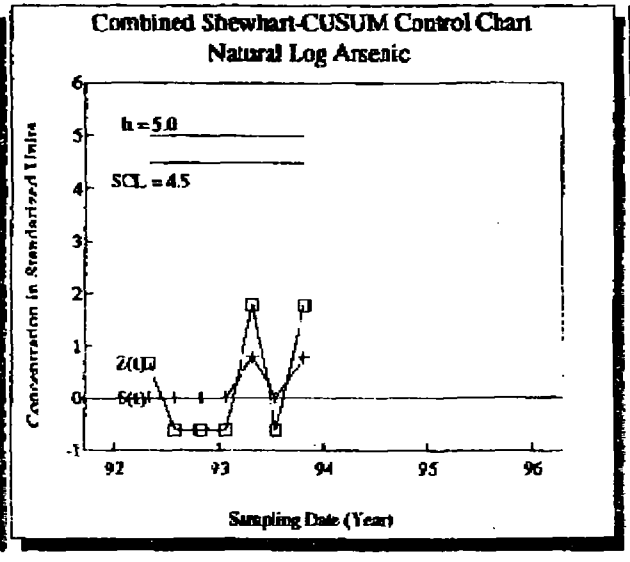
U.S. EPA (1989; February) *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities -- Interim Final Guidance*. Office of Solid Waste, Permits & State Programs Division.

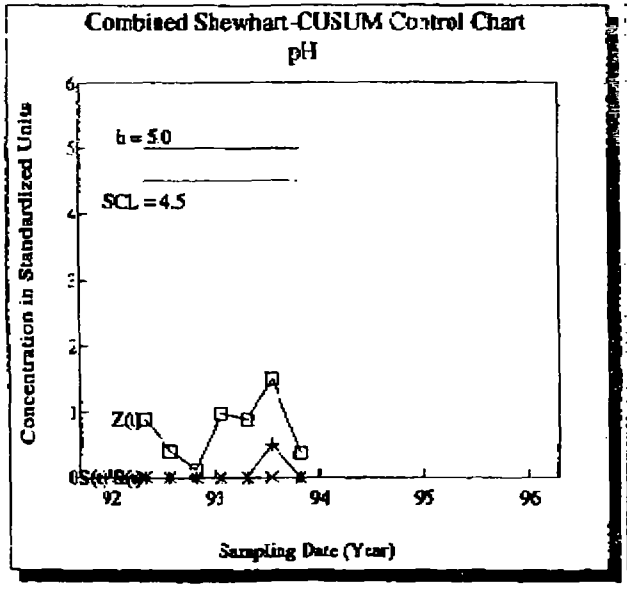
CONTROL CHARTS FOR MONITORING WELL 153

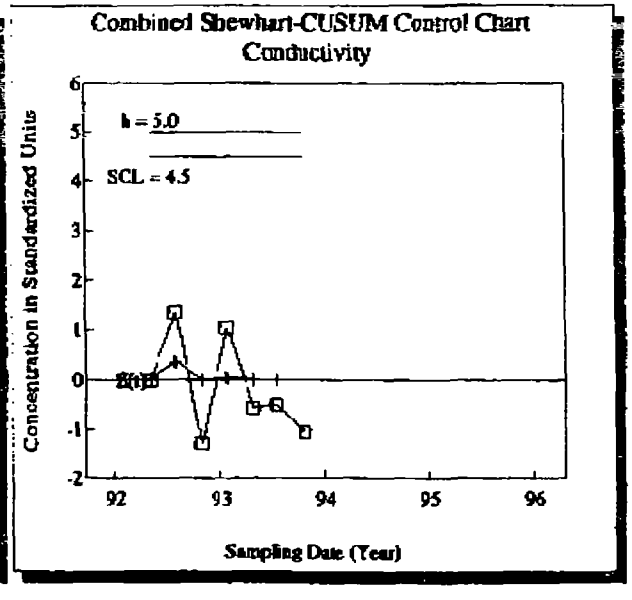
Lower Aquifer

[redacted]









WW Engineering & Science
Environmental Services Division

The control charts shown here are constructed using the methodology outlined in the US EPA document entitled "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim final Guidance, February, 1989"

Z(t) = Standarized Values
(absolute value for pH only)
S(t) = CUSUM
S(t) low = Lower CUSUM (pH only)

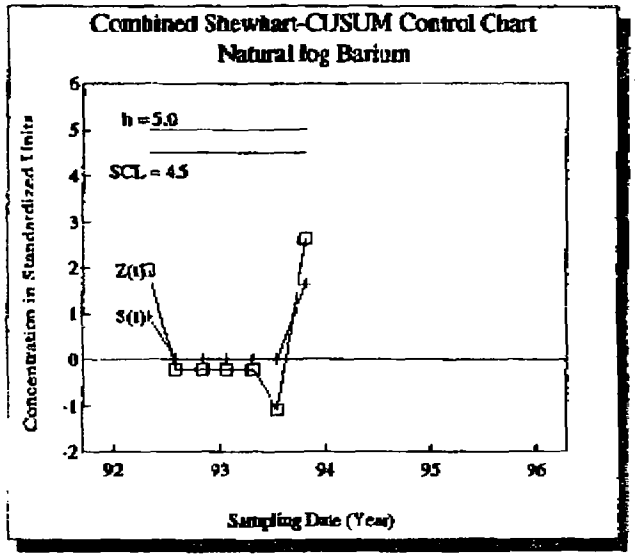
If S(t) or S(t) low > h, conclude a statistically significant difference.
If Z(t) > SCL for two consecutive sampling events, conclude a statistically significant difference.

[redacted]

Printed: 07-Apr-94

CONTROL CHARTS FOR MONITORING WELL 110
Upper Aquifer

[redacted]

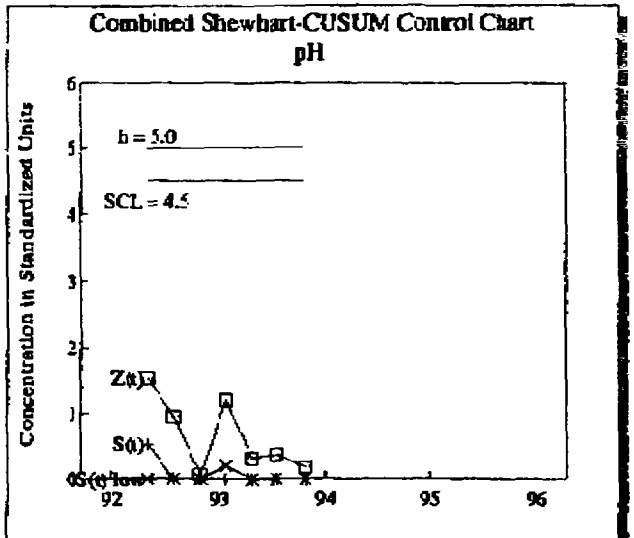


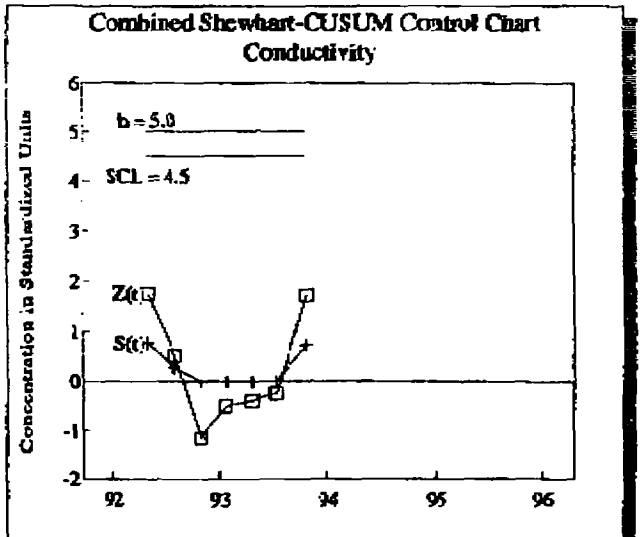
WW Engineering & Science
Environmental Services Division

The control charts shown here are constructed using the methodology outlined in the US EPA document entitled "Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim final Guidance, February, 1989"

Z(t) = Standarized Values
(absolute value for pH only)
S(t) = CUSUM
S(t) low = Lower CUSUM (pH only)

If S(t) or S(t) low > h, conclude a statistically significant difference.
If Z(t) > SCL for two consecutive sampling events, conclude a statistically significant difference.





[redacted]

Printed: 07-Apr-94